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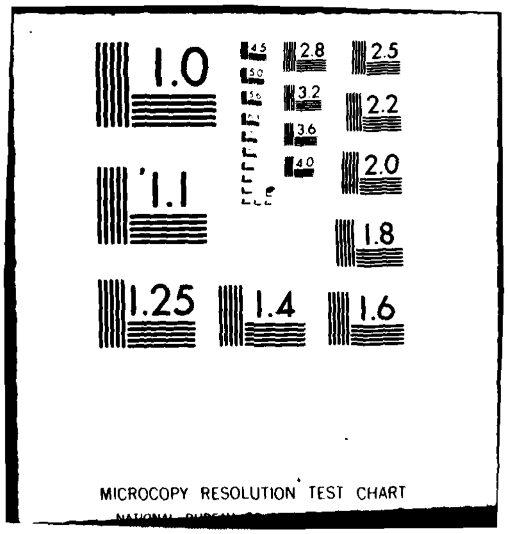
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Special Report 82-5

April 1982

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Plant growth and management for wastewater treatment in overland flow systems

Antonio J. Palazzo

Prepared for
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OVERLAND FLOW RESEARCH REPORTS

This is one of a series of reports on wastewater treatment by overland flow published by the U.S. Army Corps of Engineers under the Land Treatment of Wastewater Research Program. Other published and available reports on this topic are listed below.

Carlson, C.A., P.G. Hunt and T.B. Delaney (1974) Overland flow treatment of wastewater. Miscellaneous Paper Y-74-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Chen, R.L. and W.H. Patrick, Jr. (1980) Nitrogen transformation in a simulated overland flow wastewater treatment system. CRREL Special Report 80-16.

Hoeppel, R.E., P.G. Hunt and T.B. Delaney (1974) Wastewater treatment on soils of low permeability. Miscellaneous Paper Y-74-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Jenkins, T.F. et al. (1979) Prototype overland flow test data: June 1977-May 1978. CRREL Special Report 79-35.

Jenkins, T.F., D.C. Leggett, C.J. Martel and H.E. Hare (1981) Overland flow: Removal of toxic volatile organics. CRREL Special Report 81-1.

Lee, C.R. et al. (1976) Highlights of research on overland flow for advanced treatment of wastewater. Miscellaneous Paper Y-76-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Martel, C.J., T.F. Jenkins and A.J. Palazzo (1980) Wastewater treatment in cold regions by overland flow. CRREL Report 80-7.

Martel, C.J., T.F. Jenkins, C.J. Diener and P.L. Butler (1982) Development of a rational design procedure for overland flow systems. CRREL Report 82-2.

Peters, R.E., C.R. Lee and D.L. Bates (1981) Field investigations of overland flow treatment of municipal lagoon effluent. Technical Report EL-81-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Special Report 82-5	2. GOVT ACCESSION NO. AD-A115	3. RECIPIENT'S CATALOG NUMBER 426
4. TITLE (and Subtitle) PLANT GROWTH AND MANAGEMENT FOR WASTEWATER TREATMENT IN OVERLAND FLOW SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Antonio J. Palazzo		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS 31299 CWIS 31297
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the Chief of Engineers Washington, D.C. 20314		12. REPORT DATE April 1982 13. NUMBER OF PAGES 29
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Land treatment
Overland flow
Plant growth
Wastewater treatment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Domestic wastewater was applied over a four-year period at various rates to three overland flow test slopes to study forage grass growth and nutrient removal. The annual application rates of nitrogen and phosphorus ranged up to 2026 and 226 kg/ha, respectively. The forage grasses were harvested three times per season. Plant yields, composition and uptake of nutrients were determined. The results show that reed canarygrass, quackgrass and Kentucky bluegrass were the most persistent grasses on the slope over the four years. Perennial ryegrass was a good plant to include in seed mixtures because it

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20. Abstract (cont'd)

became established rapidly. Tall fescue and orchardgrass persisted on the slope during the initial three years of the study and then declined after high rates of wastewater were applied during the third winter. On all wastewater-treated slopes the grasses appeared to be healthy and vigorous. The major limitations to plant growth were winter injury, the deposition of wastewater solids, the development of channels on the slopes, and the invasion of barnyardgrass, which crowded out more desirable perennial grasses. Plant yields ranged from 7.6 to 12.2 metric tons/ha and increased with increasing annual loading rates of nitrogen up to 1300 kg/ha. Yields declined at the highest loading rate of about 2000 kg/ha. Plant yields were more than three times higher than the normal hay yields in this area, but they were lower than those produced at an adjacent slow rate test site. The chemical composition of the hay was within the limits for normal plant growth, and the hay was of excellent quality. The average yield was worth $862/ha. Like nutrient uptake, biomass accumulation was greatest during the first harvest period. Plant uptake of nitrogen and phosphorus increased as the loading rates of these elements increased, and leveled off or decreased at the highest loading rate. The annual plant uptake of nitrogen and phosphorus ranged from 210 to 332 and 27 to 48 kg/ha, respectively. Nutrients were removed most rapidly during the first harvest period. The system removed 58% and 48% of the nitrogen and phosphorus applied, respectively.

PREFACE

This report was prepared by Antonio J. Palazzo, Research Agronomist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

Funding for this research was provided by U.S. Army Corps of Engineers Civil Works Research and Investigation Projects CWIS 31299, Evaluation of Techniques of Overland Flow in Cold Regions, and CWIS 31297, Optimization of Management Techniques for Wastewater Renovation.

The author thanks Thomas F. Jenkins, C. James Martel, Sherwood Reed and Dr. C.E. Clapp for their reviews and constructive comments on the manuscript; John M. Graham, Carl Diener, and Bruce Ashley for technical assistance; Patricia Schumacher for wastewater analysis information; and Dr. Harlan McKim for his support as Program Manager.

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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INTRODUCTION

Overland flow is the mode of land application normally considered for wastewater treatment in areas with heavy, tight soils and gently sloping terrain. Wastewater is applied to the upper sections of the slope and is allowed to flow as a thin sheet over the soil surface. At the base of the slope the water is collected for discharge. As with slow rate systems, the wastewater is renovated by physical, chemical and biological processes.

Although there is renewed interest in the use of land treatment, very little information is available about plant growth in overland flow systems. Much of our knowledge on crop growth in these systems is extrapolated from slow rate sites or conventional agricultural studies.

Although both slow rate and overland flow systems are land treatment processes, the plant growth environments they provide differ significantly. These environments are also considerably different from most areas where agricultural plants are normally grown. The three major differences are the direction of water movement, the residence time of water within the system boundaries, and the types of soil in the system. In overland flow the water moves by sheet flow over the soil surface and the residence time is shorter, both of which result in less interaction of the water with the soil than in slow rate systems. Also, the soils have a heavier texture, which impedes air movement and plant growth. These differences affect the degree of treatment of the various wastewater constituents and the growth of plants.

Vegetation selection and management should include plants that can be established rapidly, have economic value, and grow well on these tight, moist soils. Because these are wet, sloping soils, they are not suitable for row crops and legumes. This limits the type of herbaceous vegetation to forage grasses.

Overland flow systems have been found to be effective for removing nitrogen (Hart 1974, Jenkins and Martel 1979, Lee and Peters 1979, McPherson 1979, Palazzo et al. 1980). These systems have also been

reported to be efficient in reducing BOD (McPherson 1979, Martel et al. 1980) and removing heavy metals (McPherson 1979, Lee and Peters 1979), volatile trace organics (Jenkins et al. 1980), and suspended matter (Jenkins and Martel 1979). Martel et al. (1980) reported that NH_4 removal is more efficient than NO_3 removal in this system.

The major weakness of overland flow systems is their inability to remove phosphorus effectively due to the lack of soil-water interaction. Some results of phosphorus removal tests have been reported by Jenkins and Martel (1979), Lee and Peters (1979) and McPherson (1979).

Only limited information is available on the importance of vegetation in removing wastewater constituents and providing an economic return from the sale of crops. Grasses that have been reported to have performed well include Italian ryegrass in Australia (McPherson 1979) and reed canarygrass in Mississippi and Texas (C.W. Thornthwaite Associates 1969, Lee and Peters 1979). Forage grass yields have been reported by Lee and Peters (1979) in Mississippi and Palazzo et al. (1980) in New Hampshire.

Proper plant management using plant and soil analyses can increase the cold tolerance of plants and help maintain their nutrient removal capability over many years. A study of winter-killing of coastal bermudagrass (*Cynodon dactylon* L.) showed that high levels of nitrogen, combined with low levels of potassium, increased winter injury (Adams and Twersky 1960). Increased winter damage due to high levels of nitrogen has also been reported by Jung and Kocher (1974), while high levels of potassium have been known to increase the cold resistance of plants (Dexter 1956, Hayden et al. 1969). Therefore, it is important to maintain optimum levels of potassium in soils and plants.

The nitrogen-potassium balance in wastewater must also be considered, since it may be insufficient to meet plant needs, leading to problems in plant growth and possibly to winter injury (Palazzo and Jenkins 1979). The total application of potassium from either wastewater or fertilizer should be approximately 90% of the amount of nitrogen removed by the crop. Nitrogen and potassium are the most important combination of elements affecting plant winter hardiness, especially for forage grasses (Kresge 1974).

Our objectives in this study were to assess plant growth and nutrient uptake to improve the agronomic design and management criteria for overland flow treatment systems. Information on the chemical composition of plants was gathered to evaluate the health and animal nutritive value of the grasses. Plant yields were recorded to assess the economic value of the forage. The botanical composition of the slope was also ascertained to compare the growth and persistence of desirable plants. Plant uptake was determined from the chemical composition and yield data to assess the degree of wastewater renovation.

MATERIALS AND METHODS

The overland flow site is located at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, and has been described in detail by Jenkins et al. (1978) and Martel et al. (1980). Hanover has a mean annual temperature of 7°C and approximately 160 days of below-freezing temperatures each year. The annual rainfall and snowfall average 95 and 185 cm, respectively. The site faces south-southwest and the prevailing winds are from the west and northwest.

The overland flow site is 8.8 m wide by 30.5 m long and is graded to a 5% slope (Fig. 1). It is divided into three equal sections, each measuring

Figure 1. View of overland flow research site.

2.9 m by 30.5 m. The soil on the overland flow slope is classified as Hartland silt loam and is made up of 5% sand ($\geq$50 μm), 72% silt (50 - 2 μm) and 23% clay ($\leq$ 2 μm). Prior to any treatments, the initial cation exchange capacity of the soil was 5 meq/100 g; the pH was 7.1. Bulk densities averaged 1.4 g/cm^3 and the specific gravity was 2.7. Underlying the soil at a depth of 15 cm is a 1.0-mm-thick rubber membrane, which prevents downward percolation. Crushed stone was placed at the top of the slope to prevent erosion and to distribute the flow evenly.

Prior to seeding, each slope received an equivalent of 2.3 metric tons/ha of dolomitic limestone and 726 kg/ha of 15-15-15 grade fertilizer, which supplied 109, 47 and 90 kg/ha of nitrogen, phosphorus and potassium, respectively.

The site was seeded on 17 September 1975 with a seed mixture containing K-31 tall fescue (Festuca arundinacea Schreb.), Pennlate orchardgrass (Phleum pratense L.), reed canarygrass (Phalaris arundinacea L.) and perennial ryegrass (Lolium perenne L.) at a rate of 120 kg/ha. The first three grasses were selected for their ability to utilize nitrogen and their tolerance for wet soil. Perennial ryegrass was chosen as a nurse crop to prevent erosion on the slope after seeding.

During 1976 the system was tested and optimized. Due to the low amounts of nutrients and water applied in 1976, grass growth was poor in the spring of 1977. Therefore, on 21 April 1977, or about six weeks before wastewater was applied, the entire site was fertilized with 55 kg/ha of nitrogen from ammonium nitrate. Subsequent fertilizations with nitrogen occurred only when wastewater applications were not anticipated and consisted of applying 60 kg/ha nitrogen on 14 June 1978 and 130 kg/ha nitrogen on 6 May 1980 to Section A. The variations in wastewater applications during this study were due to the application requirements of other short-term research studies being carried out on these slopes. Large applications of potassium were applied to offset any deficiencies of this element. Previous studies in slow rate systems have shown that potassium can be a limiting factor for plant growth and that application rates of this element can be based on the amount of nitrogen that is applied (Palazzo and Jenkins 1979). Therefore, 220 kg/ha of potassium from potassium chloride and 2.3 metric tons/ha of dolomitic limestone was applied on 21 April 1977. We also applied 110 kg/ha of potassium to Section A and 167 kg/ha of potassium to Sections B and C on 6 May 1980.

Domestic sewage from the town of Hanover was applied throughout the year. The wastewater was applied at the top of the slope through perforated plastic pipe, which could be back-drained when not in use. The runoff was collected at the base of the slope in large galvanized steel tanks. Flowmeters were used to monitor the volumes of water applied and collected.

Each weekly application was applied over a five-day period, seven hours per day. The wastewater was analyzed daily, as reported by Jenkins and Palazzo (1981), to determine the amount of nutrients applied. It was generally nearly neutral in pH and contained an average of 35 mg/L of total nitrogen, mainly in the ammonium form, and 6 mg/L of total phosphorus. Wastewater applications began on 1 June 1977 and, for the purposes of this study, ended in September 1980.

The forages were managed on a conventional three cuts per year schedule. The grass was cut with a sickle-bar mower set at a 7.5-cm height; the grass was then hand-raked and weighed to obtain the total fresh weights per section. Representative subsamples from each section were washed in distilled water and dried at 70°C for 48 hours to determine the total dry weight yields. Grab samples of the grasses were analyzed for nitrogen, phosphorus, potassium and six minor elements using the methods of Liegel and Schulte (1977).

RESULTS AND DISCUSSION

Loading rates

The annual loading rates were determined by totaling the amounts of wastewater applied between harvests. This included all the wastewater applied during the winter before the first harvest period. The winter loading rates were usually high. Therefore, the efficiency of plant uptake would have appeared to be higher if the applications during the winter, when the plants were dormant, had not been included in the totals.

The annual nitrogen and phosphorus loading rates ranged up to 2038 and 228 kg/ha, respectively (Table 1). The highest loading rates are probably beyond what would normally be used for efficient nitrogen and phosphorus removal.

Due to other research studies on the slopes during this time, wastewater applications were not consistent over the harvest periods (Table 1). Years in which wastewater was applied in at least two of the three harvest

Table 1. Amounts (kg/ha) of nitrogen and phosphorus applied prior to each harvest.

	Date	Harvest Number First	Second	Third	Total
Nitrogen					
Section A	1977	--	97	98	195
	1978	655	0	279	934
	1979	331	0	0	331
	1980	0	0	0	0
Section B	1977	--	96	110	206
	1978	587	0	280	867
	1979	354	361	585	1300
	1980	1704	209	113	2026
Section C	1977	--	1	1	2
	1978	2	0	236	238
	1979	336	321	603	1260
	1980	1702	221	115	2038
Phosphorus					
Section A	1977	--	17	18	35
	1978	106	0	50	156
	1979	56	0	0	56
	1980	0	0	0	0
Section B	1977	--	19	20	39
	1978	95	0	56	151
	1979	60	70	98	228
	1980	280	12	8	300
Section C	1977	--	2	1	3
	1978	5	0	43	48
	1979	57	61	98	216
	1980	203	13	8	224

periods were 1978 on Section A; 1978, 1979 and 1980 on Section B; and 1979 and 1980 on Section C.

Botanical composition

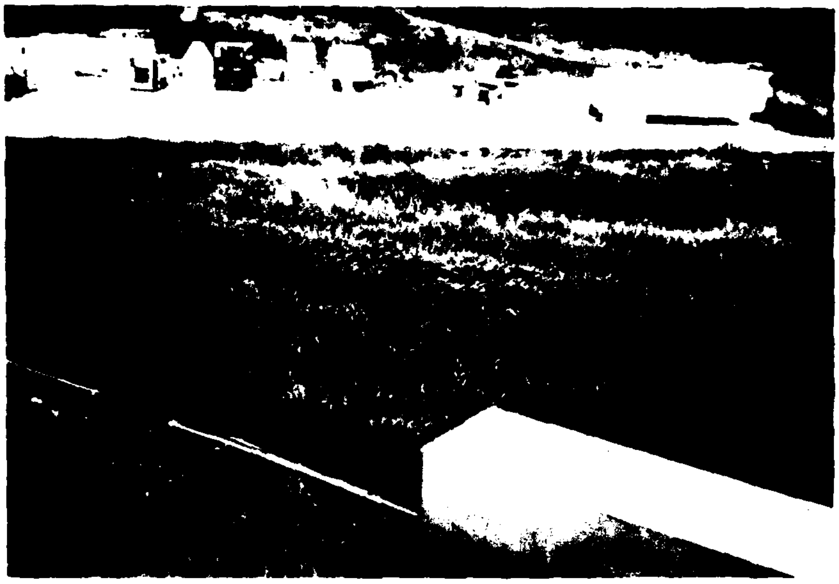
It is important to maintain a vigorous community of desirable plants on overland flow slopes. If a healthy community is not maintained, soil erosion will result in the development of small channels, which will reduce the efficiency of the treatment. If the sown species are replaced by weeds, nitrogen and phosphorus uptake will be reduced, resulting in poor wastewater renovation. In addition, if less desirable species predominate, the market value of the crop will drop or costly reseeding operations will be necessary, increasing the overall operation and management costs.

Of the four grasses, orchardgrass and tall fescue were the most persistent over the initial three years of wastewater application. These species germinated well under low nutrient conditions. Perennial ryegrass established well after seeding; however, after two winters of wastewater application few plants of this species survived. This low survival rate was probably due to winter injury, to which ryegrass is known to be sensitive.

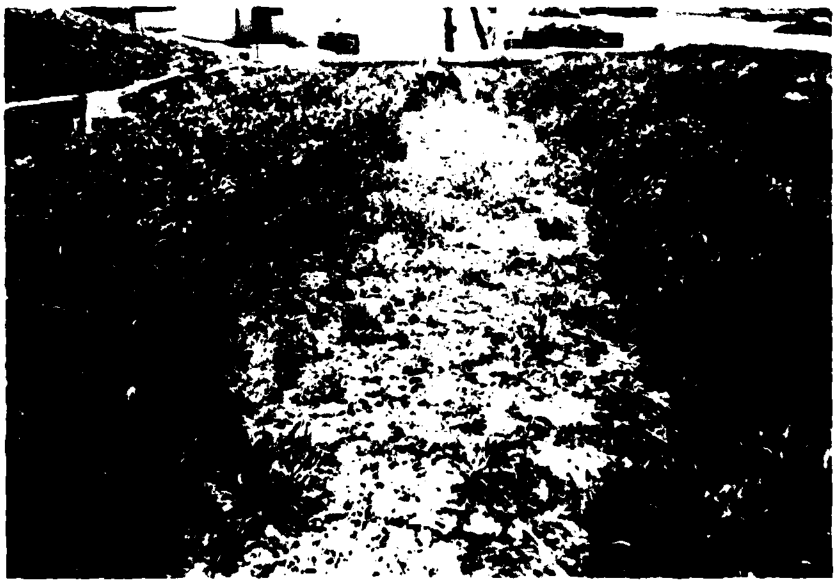
Reed canarygrass did not become established well on the site initially. This grass is slow to germinate and requires large amounts of nutrients and water to grow actively. Since only a small amount of fertilizer was applied during seeding, the soil apparently was not fertile enough for adequate growth. After wastewater applications began in 1977, the growth of this grass improved, and it became a more dominant species on the site by the fourth season. As a result, we recommend that commercial fertilizers be applied at light rates (50 kg/ha each of nitrogen, phosphorus and potassium) to overland flow slopes after system construction if delays in wastewater application are expected. The fertilizer will maintain a healthy grass stand and result in better performance once the system goes into operation.

Kentucky bluegrass and quackgrass invaded the site as the study progressed. These species have been observed to remove large amounts of nutrients in experiments on slow rate systems (Palazzo and McKim 1978, Marten et al. 1979). Kentucky bluegrass is an excellent forage and appears to tolerate wet soils. Quackgrass, considered a poor forage species for animal feed under conventional agricultural management, has been observed to be of excellent quality when irrigated with wastewater (Marten et al. 1978). Therefore, both of these species can be acceptable components of the grass mixture on overland flow slopes.

Barnyardgrass, another invading species, also became dominant on the slope during 1979. The opportunity of barnyardgrass to become established probably began the previous season, when wastewater solids smothered more desirable plants at the top of the slope. Peters et al. (1981) reported large areas of dead grass and barnyardgrass at the upper part of an overland flow slope in Mississippi. Barnyardgrass is an annual that germinates from seed in the spring and becomes tall and aggressive. During the summer of 1979, barnyardgrass replaced the desirable grasses on the site, but in the fall it died, leaving the slope barren of vegetation and susceptible to soil erosion until the following spring (Fig. 2). Since it crowds out



a. Tall, aggressive barnyardgrass during the summer of 1979.



b. Same slope the following spring.

Figure 2. Barnyardgrass on the middle slope of the overland flow system.

desirable plants, the growth of this plant should be controlled. Barren areas should be reseeded with high-yielding perennial plants.

At the end of the study (October 1980) the grasses receiving wastewater on Sections B and C were healthy and vigorous. Sections B and C had received wastewater on a daily basis, while Section A had not been irrigated with wastewater for 15 months (low nutrient condition). In terms of botanical composition, the site can be divided into three areas: the upper and lower sections of the treated slopes and the low nutrient area.

In the upper portions of Sections B and C, where the deposition of solids was greatest, the grasses consisted primarily of quackgrass, reed canarygrass and smaller amounts of Kentucky bluegrass. The grasses did not cover as much of the soil in this area as they did in the lower parts of the slope. The barren areas were generally where the barnyardgrass died out. In the lower halves of Sections B and C the predominant grass was Kentucky bluegrass, with lesser amounts of orchardgrass and very little reed canarygrass. In Section A, Kentucky bluegrass, orchardgrass, quackgrass and tall fescue were present. As with perennial ryegrass, tall fescue did not survive in areas on the slope that received high loading rates of wastewater after the third season. In both treated sections (B and C) the dominant grasses looked healthy and vigorous.

The decline in tall fescue after the third growing season appears to be related to the very high rates of wastewater applied during the previous winter (Table 1). Orchardgrass was also affected. Ice cover or crusts over the grasses that develop due to cold weather applications led to winter injury and barren soil areas (Fig. 3). This crust could have prevented the exchange of gases required for plant metabolism (Dexter 1956).

Plant yields

During years when wastewater was applied for a minimum of two harvest periods, the annual dry weight ranged from 7.6 to 12.2 metric tons/ha (Table 2). The mean yield was 9.7 metric tons/ha. When little or no wastewater was applied, the yields ranged from 1.1 to 7.4 metric tons/ha.

The average yield when wastewater was being applied was almost three times the normal hay yield in New Hampshire (New England Crop and Livestock Reporting Board 1978), but it was lower than the 10.77-13.84 metric tons/ha reported for an overland flow site in Mississippi (Peters et al. 1981).

a. Ice buildup at lower part of slope due to winter application of wastewater in February 1980.

b. Areas barren of vegetation during the following spring.

Figure 3. Development of barren areas.

Table 2. Plant yields (metric tons/ha) by harvest periods at the overland flow test site.

Date	Harvest Number First	Second	Third	Total
		Section A		
1977	-	1.8	2.0	3.8+
1978	3.6	3.6*	1.5	8.7
1979	4.1	1.4*	1.9*	7.4+
1980	2.0*	0.8*	0.4*	3.2+
		Section B		
1977	-	1.6	1.9	3.5+
1978	2.9	5.0*	1.5	9.4
1979	4.6	4.1	3.4	12.1
1980	2.0	3.5	2.1	7.6
		Section C		
1977	-	0.5*	0.6*	1.1+
1978	0.3*	2.7*	2.0	5.0+
1979	3.2	3.7	3.8	10.8
1980	3.7	2.3	3.5	9.5
Mean	2.9	2.6	2.0	

* Harvest periods when wastewater was not applied.

+ Growing seasons in which wastewater was not applied during two or more harvest periods or where three harvests were not taken.

At the CRREL slow rate site, yields of a mixed forage grass averaged 13.1 metric tons/ha and ranged from 7.4 to 17.6 metric tons/ha over a seven-year period (Jenkins and Palazzo 1981).

The value of the hay can be determined by adding 15% to the dry weight yields to account for the moisture in hay. The average hay yield in this study would then be about 11.2 metric tons/ha. If we assume that hay is worth about $77/metric ton ($70/English ton), then the annual value of one hectare of hay is $862 ($349/acre), which is about 300% greater than the hay harvested from conventional hay fields.

As shown in Figure 4, plant yields increased with increasing application rates of nitrogen up to about 1200-1300 kg/ha. At applications of

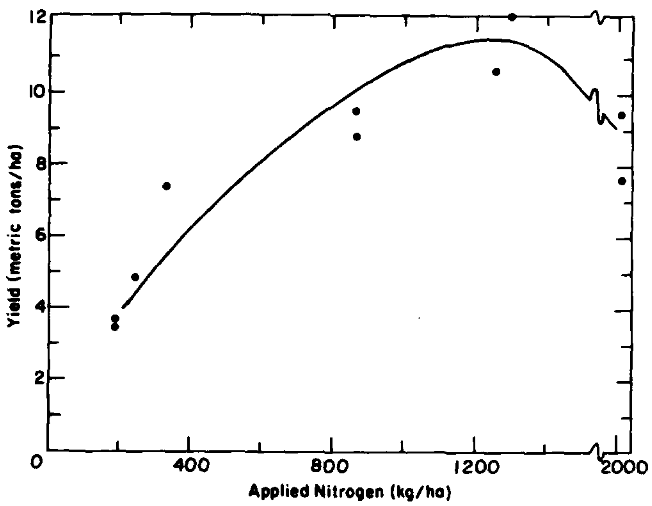


Figure 4. Annual plant yields under continuous nitrogen loading rates throughout the year.

about 2000 kg/ha yields declined; the reason for this is unclear. On Section B, which yielded about 7600 kg/ha in 1980, the decline appears to be partially related to the dominance of barnyardgrass, which left large barren areas when it died. Another reason could be the large amounts of water applied during this period, which could have injured plants or reduced the depth of aerated soil.

Average yields were found to be highest in the first harvest period; they declined slightly in the second and third periods (Table 2). Since the first harvest period was the shortest, the mean daily growth of plants during that period was far greater. The mean daily growth was 96, 50 and 34 kg/ha for the first, second and third harvest periods, respectively. A similar trend was reported for a two-year study at an adjacent slow rate site (Palazzo and Graham 1981).

The forage grasses from Sections B and C were tested for feed quality during the last cuttings in 1979 and 1980 (Table 3). They contained an average of 22% crude protein and 85% total digestible nutrients. Barnes (1975) reported that grass hay having 15% or more crude protein and 65% or more total digestible nutrients is excellent in quality.

Plant analysis

The plants were analyzed for nine elements at each harvest (Table 4). None of the concentrations were in the deficiency or toxicity ranges, indicating that the plants were healthy under the management schemes used in this study.

Table 3. Feed quality of forage grasses and reported standards for high quality feed.

Date of harvest	Section	Crude protein (%)	TDN*(%)
15 October 1979	B	18	69
30 September 1980	B	26	101
15 October 1979	C	21	69
30 September 1980	C	24	99
Mean	-	22	85
Barr and Staubus (1980)		15-16	70-75
Barnes (1975)		>18	>65

* Total digestible nutrients

Table 4. Mean concentrations of elements in the grasses.

Element	Concentration
Nitrogen	2.83 (%)
Phosphorus	0.41 (%)
Potassium	2.45 (%)
Calcium	0.53 (%)
Magnesium	0.25 (%)
Boron	5.4 ppm
Copper	9.1 ppm
Zinc	36.0 ppm
Manganese	81.0 ppm

Plant uptake of nitrogen and phosphorus

When wastewater was applied, annual plant uptake ranged from 210 to 332 kg/ha of nitrogen and from 27 to 48 kg/ha of phosphorus (Table 5). During seasons with smaller applications of wastewater, plant uptake was lower; nitrogen and phosphorus uptake ranged from 28 to 168 and 4 to 27 kg/ha, respectively.

The rate of nutrient uptake initially increased with increasing wastewater loading rates and then either leveled off or decreased at the highest loading rates (Figs. 5 and 6). The greatest loading rates occurred on Sections B and C in 1980 (Table 1). The lower uptake on Section B, which amounted to 106 kg/ha less nitrogen than on Section C (Table 5), was primarily related to the lack of vegetation on this slope. This crop response differs from the results in Mississippi, where plant uptake did

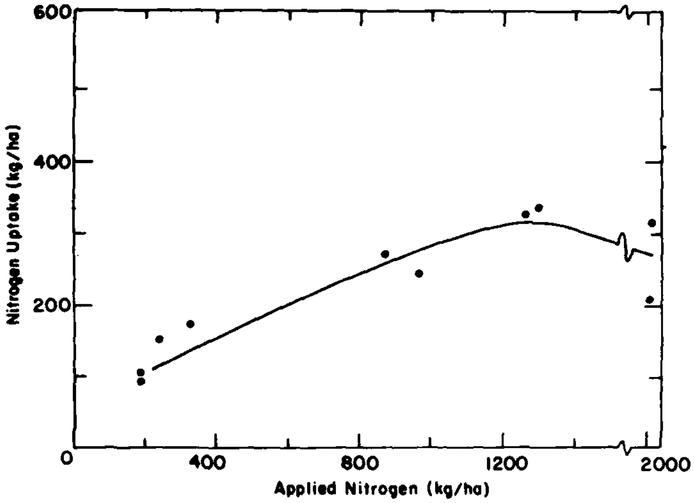


Figure. Annual plant uptake of nitrogen at various nitrogen loading rates.

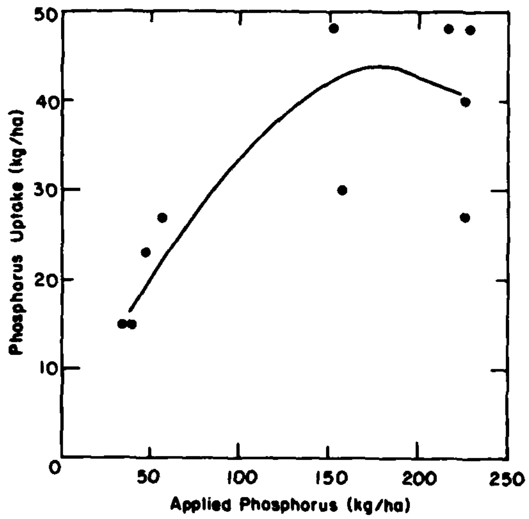


Figure 6. Annual plant uptake of phosphorus under continuous phosphorus loading rates throughout the year.

not increase when the rate of wastewater application was increased (Peters et al. 1981).

The mean daily plant uptake of nitrogen and phosphorus during each harvest period is shown in Table 6. The most rapid uptake of nutrients occurred during the first harvest period when plants incorporated an average of 2.8 and 0.4 kg/ha of nitrogen and phosphorus, respectively. The

Table 5. Plant uptake (kg/ha) of nitrogen and phosphorus at the overland flow test site.

	Date	Harvest Number First	Second	Third	Total
			Nitrogen		
Section A	1977	-	46	61	107+
	1978	118	82*	43	243
	1979	103	36*	29*	168+
	1980	71*	19*	12*	102+
Section B	1977	-	50	41	91+
	1978	84	137*	51	272
	1979	139	108	85	332
	1980	45	96	69	210
Section C	1977	-	14*	14*	28+
	1978	8*	83*	60	151+
	1979	93	108	124	325
	1980	112	69	135	316
			Phosphorus		
Section A	1977	-	7	8	15+
	1978	19	16*	5	40
	1979	15	5*	7*	27+
	1980	6*	3*	2*	11+
Section B	1977	-	7	8	15+
	1978	15	26*	7	48
	1979	18	17	13	48
	1980	7	12	8	27
Section C	1978	-	2*	2*	4+
	1977	1*	12*	9	22+
	1979	13	18	17	48
	1980	14	9	17	40

* Harvest periods when wastewater was not applied.

+ Entire growing seasons in which wastewater was not applied during two or more harvest periods or where three harvests were not taken.

rate of daily uptake was similar to that at an adjacent slow rate system (Palazzo and Graham 1981).

Nitrogen and phosphorus removal

During the study a total of 9397 kg/ha of nitrogen was applied to the three test slopes (Table 7). While the total amount of nitrogen uptake

Table 6. Mean daily plant uptake of nitrogen and phosphorus on the overland flow slopes.

Harvest period	Days of growth	Nitrogen uptake (kg/ha)	Phosphorus uptake (kg/ha)
First (May-June)	36	2.8	0.4
Second (June-July)	57	1.4	0.2
Third (July-October)	71	1.1	0.1

Table 7. Nitrogen balance sheet.

Section	Applied (kg/ha)	Plant uptake (kg/ha)	Plant uptake (%)	Runoff (kg/ha)	Runoff (%)	Unaccounted for (kg/ha)	Unaccounted for (%)
A	1460	620	42	595	41	412	17
B	4399	905	21	1938	44	1556	35
C	3538	820	23	1580	45	3116	32
Total	9397	2345	25	4113	44	4103	33

generally increased with increasing amounts applied, the percentage removed by the plants decreased as the amount of this element applied on each slope increased (Table A2). Plant uptake ranged from 21 to 42%. The amount of nitrogen unaccounted for ranged from 17 to 35% and was related to the application rate of this element. The portion of the applied nitrogen found in the runoff stayed relatively constant, ranging from 41 to 45%. The average total removal of the applied nitrogen by the entire system was 58% and varied only slightly, regardless of the application rate of this element.

The percentage of nitrogen removed by the forage grasses is lower than what is normally expected in slow rate systems at comparable loading rates (Jenkins and Palazzo 1981). This is due primarily to the high annual rate of wastewater applied, the large percentage of wastewater applied during the winter, and possibly the shorter residence time of the wastewater on the slope than in slow rate systems. Therefore, it would not be surprising to find greater plant uptake on slopes that receive a lower rate of wastewater but with a large percentage of it being applied during the growing season.

Table 8. Phosphorus balance sheet.

Section	Applied (kg/ha)	Plant uptake (kg/ha)	(%)	Runoff (kg/ha)	(%)	Unaccounted for (kg/ha)	(%)
A	247	93	34	100	40	54	22
B	644	138	21	340	53	165	26
C	491	114	23	279	57	98	20
Total	1381	345	25	719	52	317	23

Overland flow systems are known to be poorer renovators of phosphorus than slow rate systems. Plant uptake of phosphorus in this study accounted for 25% of the phosphorus applied; runoff accounted for another 52% (Table 8, A3). The total amount of phosphorus removed by the system was 48% of the amount applied. This agrees with the 40-60% reduction in phosphorus found by Peters et al. (1981).

CONCLUSIONS AND RECOMMENDATIONS

This study showed that forage grasses grew well when wastewater was applied to an overland flow treatment system. Reed canarygrass, orchardgrass and tall fescue had good persistence on the slopes during the study. Perennial ryegrass was dominant early in the study and was effective in removing nutrients and preventing soil erosion while the perennial grasses became established. Kentucky bluegrass and quackgrass were also found to be acceptable species.

Plant selection should be limited to forage grasses, since they are more tolerant of wet soils and are capable of removing more nitrogen than row crops or legumes. Seed mixtures containing perennial ryegrass and two or three of the other species should be suitable for overland flow systems.

Since the terrain is gently sloping, grasses should be established at the proper seeding time during the year and as soon after grading as possible to minimize soil erosion and channeling. The slope can be fertilized and irrigated to help the plants become established faster.

High plant yields can be expected on overland flow systems. Yields in this study were almost three times greater than the normal hay yield in New Hampshire; yields ranged from 7.6 to 12.2 metric tons/ha when wastewater was applied during the entire growing season. The quality of the

forage in terms of crude protein and total digestible nutrients was excellent, and the mean yield (11.2 metric tons/ha) was worth about $862/ha.

During the four-year period the overland flow system removed an average of 58 and 48% of the nitrogen and phosphorus applied, respectively. Increases in the application rate decreased the percentage of nitrogen taken up by the plants and increased the percentage of this element that was unaccounted for. Increases in this rate had little effect on the percentage of nitrogen found in the runoff.

The annual plant uptake during seasons of wastewater application was 210-332 kg/ha of nitrogen and 27-48 kg/ha of phosphorus. The uptake initially increased with increasing loading rates and then leveled off. The rate of plant uptake was highest during the first harvest period.

Proper management is important to maintain grass growth and uptake. This study showed that grasses should receive light applications of commercial fertilizer (about 50 kg/ha each of nitrogen, phosphorus and potassium) if delays in wastewater applications occur after seeding.

Certain annual weeds should be controlled. In this study barnyardgrass crowded out the more desirable perennial grasses and reduced plant uptake on the slope.

To grow fast and remove a high percentage of nutrients, plants must be healthy. The chemical composition of the grasses should be checked periodically to determine nutrient deficiencies or toxicities. Plant analysis and management recommendations are usually provided at state agricultural experiment stations. Prior analysis of the wastewater will indicate specific elements of concern; they include those required by plants for growth and those that may be toxic (particularly metals).

Grasses should also be managed to increase their tolerance to cold. The amount of potassium applied should be 90% of the amount of nitrogen removed by the plant. Again, wastewater should be analyzed to determine if supplemental potassium applications are required.

Wastewater solids should be controlled so that grass will not be smothered at the point where wastewater is applied. Bare areas should be reseeded with desirable species as soon as possible to prevent weed encroachment and to improve plant uptake.

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APPENDIX A: ANALYSIS OF NUTRIENTS

Table A1. Plant concentrations of nutrients at the overland flow test site.

Date	Harvest Period First	Harvest Period Second	Harvest Period Third	Harvest Period First	Harvest Period Second	Harvest Period Third
Section A		Nitrogen			Phosphorus	
1977	-	2.60	3.07	-	0.41	0.42
1978	3.26	2.27	2.87	0.52	0.44	0.33
1979	2.51	2.48	1.56	0.37	0.37	0.35
1980	3.49	2.37	2.84	0.31	0.33	0.35
		Potassium			Calcium	
1978	2.30	2.46	1.72	0.43	0.48	0.54
1979	2.01	2.24	2.15	0.34	0.60	0.43
1980	2.41	2.69	2.26	0.47	0.61	0.49
		Magnesium			Boron	
1978	0.25	0.40	0.19	5.0	5.5	3.0
1979	0.18	0.32	0.25	4.5	6.5	3.5
1980	0.13	0.26	0.25	5.3	9.3	6.8
		Copper			Zi	
1978	11.0	8.0	6.0	46.0	46.0	18.0
1979	8.5	7.0	5.5	34.0	29.5	28.0
1980	11.2	7.4	8.0	26.8	17.5	27.8
		Manganese				
1978	75	232	55			
1979	41	62	44			
1980	34	47	48			
Section B		Nitrogen			Phosphorus	
1977	-	3.14	2.25	-	0.45	0.43
1978	2.86	2.72	3.35	0.50	0.51	0.48
1979	3.00	2.64	2.48	0.39	0.42	0.38
1980	2.22	2.73	3.35	0.36	0.33	0.39
		Potassium			Calcium	
1978	3.14	3.42	2.05	0.43	0.42	0.53
1979	2.03	2.28	2.42	0.38	0.54	0.47
1980	2.63	2.69	2.11	0.31	0.60	0.49
		Magnesium			Boron	
1978	0.27	0.19	0.21	5.0	5.0	4.5
1979	0.18	0.32	0.22	4.0	5.5	3.5
1980	0.13	0.30	0.31	6.4	6.9	5.8
		Copper			Zinc	
1978	11.0	8.0	9.0	49.0	25.0	32.5
1979	8.5	11.0	6.5	33.5	48.5	26.5
1980	8.4	11.9	9.8	33.9	31.0	44.7
		Manganese				
1978	56	115	71			
1979	45	135	45			
1980	50	148	82			
Section C		Nitrogen			Phosphorus	
1977	-	2.53	2.39	-	0.37	0.35
1978	3.08	3.08	3.06	0.41	0.49	0.46
1979	2.96	2.92	3.26	0.42	0.48	0.44
1980	3.02	3.03	3.88	0.39	0.38	0.49
		Potassium			Calcium	
1978	3.35	3.17	2.08	0.90	0.47	0.68
1979	2.34	2.48	2.54	0.40	0.63	0.50
1980	2.33	2.15	2.35	0.35	0.58	0.51
		Magnesium			Boron	
1978	0.29	0.38	0.27	5.5	4.5	5.5
1979	0.21	0.30	0.24	3.5	5.5	4.0
1980	0.16	0.28	0.32	5.6	6.9	6.9
		Copper			Zinc	
1978	9.0	9.5	9.0	27.5	37.0	28.5
1979	10.0	9.0	9.5	42.0	30.5	32.0
1980	8.1	11.2	12.8	36.3	37.5	79.7
		Manganese				
1978	89	89	77			
1979	52	117	61			
1980	84	113	208			

Table A2. Nitrogen balance sheet (kg/ha).

Section and year	Applied	Plant uptake	Runoff	Unaccounted for
Section A				
1977	195	107	16	
1978	934	243	380	
1979	331	168	199	
1980	0	102	0	
Total	1460	620 (42%)	595 (41%)	412 (17%)
Section B				
1977	260	91	32	
1978	867	272	433	
1979	1300	332	599	
1980	2026	210	874	
Total	4399	905 (21%)	1938 (44%)	1556 (35%)
Section C				
1977	2	28	4	
1978	238	151	110	
1979	1260	325	556	
1980	2038	316	900	
Total	3538	820 (23%)	1570 (44%)	1148 (32%)
Grand total	9397	2345 (25%)	4103 (44%)	3116 (33%)

Table A3. Phosphorus balance sheet (kg/ha).

Section and year	Applied	Plant uptake	Runoff	Missing
Section A				
1977	35	15	4	
1978	156	40	63	
1979	56	27	33	
1980	0	11	0	
Total	247	93 (38%)	100 (40%)	54 (22%)
Section B				
1977	38	15	9	
1978	151	48	73	
1979	228	48	136	
1980	226	27	122	
Total	643	138 (21%)	340 (53%)	165 (26%)
Section C				
1977	3	4	1	-2
1978	48	22	21	17
1979	216	48	137	44
1980	224	40	120	63
Total	491	114 (23%)	279 (57%)	98 (20%)
Grand total	1381	345 (25%)	719 (52%)	317 (23%)